Statistical and Stochastic Problems in Ocean Modeling and Prediction

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LONG-TERM GOALS

My project addresses statistical and stochastic problems in the following fields: Lagrangian prediction (1), Lagrangian data assimilation (2), development and validation of Lagrangian stochastic models (LSM) (3). The long range scientific objectives of this study comprise rigorous determining limits of predictability for Lagrangian motion in semi-enclosed seas, littoral zones, and straits on time scales of days and weeks, elaborating concrete prediction schemes, developing optimal Lagrangian data assimilation algorithms, and identification of multi particle stochastic models aimed at incorporating them to ocean circulation models (OCM).

OBJECTIVES

The objectives for the second year of research were:

- Completion of a Lagrangian subgridscale model for improvement of particle transport prediction
- Development of a quasi-optimal interpolation algorithm for Eulerian velocity field given Lagrangian observations
- Extension of multi particle LSMs suggested in (Piterbarg, 2001) to the anisotropic case with non-local dynamics and development of parameter estimation methods in such models
- Parameterization of the eddy birth/death processes via a stochastic model

APPROACH

I develop theoretical approaches to the Lagrangian prediction/control and Lagrangian data assimilation problem as well as to the material transport and mixing problem, in context of the theory of random processes and fields covered by stochastic partial differential equations. I design computational algorithms derived from the theoretical findings. A significant part of validating the algorithms is testing them via stochastic simulations. Such an approach provides us with an accurate error analysis. Together with my collaborators from Rosenstiel School of Marine and Atmospheric Research (RSMAS), ENEA (Rome, Italy), Koç University (Istanbul, Turkey) we implement the algorithms in concrete ocean models such as QG, MICOM , and NCOM as well as carry out statistical analysis of real data sets by means of new methods.

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WORK COMPLETED

1. Lagrangian prediction.

A method is developed in order to reduce errors in numerical Lagrangian transport prediction by employing the drifter statistics estimated from observational data sets. The theoretical approach is based on a Lagrangian sub-grid-scale (LSGS) model derived from the LSM developed on the previous stage of the project (Piterbarg, 2001).

Then, the method is tested using both, a common stochastic velocity field model representing an idealized turbulent flow, and the NCOM configured in the Adriatic Sea for realistic, high-resolution, complex ocean flows.

2. *Assimilation.*

The problem of Lagrangian data assimilation in an Eulerian model is formulated as an optimal filtering problem. Under the idealistic assumption that the Eulerian velocity field is delta-correlated in time (Kraichnan model) the exact solution of the non-linear filtering problem is found. In a more realistic Markov model with finite correlation time an approximation to the optimal solution is suggested and examined by Monte Carlo means. The approach gives a support to the assimilation scheme used in (Molcard et al, 2003 and Ozgokmen et al, 2003) and at the same time allows to essentially improve it. An accompanying theoretical study addresses the relative efficiency and computational cost of the following three type of estimating velocity: the best linear estimator, estimator based on a linearization of the Eulerian/Lagrangian relation and the best non-linear estimator.

3. Validation and identification of stochastic models for Lagrangian motion.

A new class of multi particle Lagrangian stochastic models is developed mimicking 2D turbulence. In particular, the suggested LSM covers non-isotropic Lagrangian turbulence and non-local dynamics. The maximum likelihood approach is used to estimate their parameters.

An error analysis is carried out by Monte Carlo means. The method allows us to satisfactorily estimate some physically important characteristics of Lagrangian motion such as relative dispersion and Lyapunov exponent by observing only one particle pair. The suggested estimation algorithm is tested by WOCE data.

To account for sub-meso-scale eddies in Lagrangain motion, we have developed a statistical procedure which allows us to identify parameters of a model stochastic velocity field known as Cinlar flow (Cinlar, 1994). Among them are the eddy center coordinates, their size and intensity, the rates of birth and death. The method is applied to recent high-resolution radar data of surface velocity between the Florida Current and the coast.

RESULTS

1. In a variety of simulation experiments it is shown that the suggested method of correction Lagrangian trajectories works satisfactorily in both, the first order Markov stochastic velocity field and the NCOM. In particular, the particle dispersion is accurately reproduced in the stochastic velocity field as can be seen from Fig.1

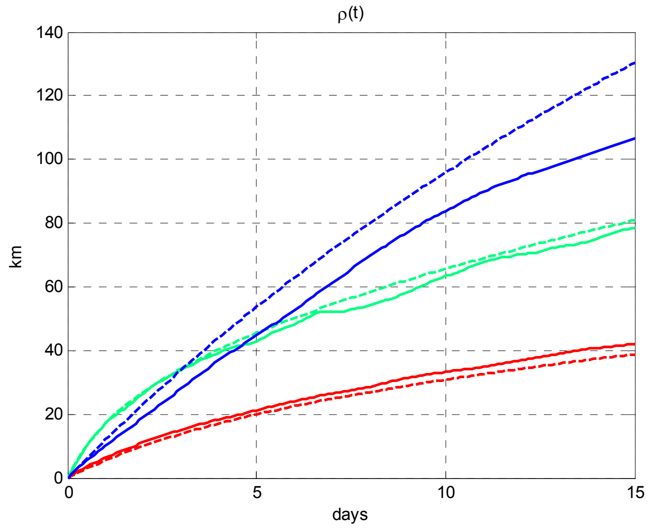

Figure 1. The dispersion curves obtained from corrected particle trajectories (solid) and that of theoretical for the underlying synthetic velocity field (broken) for three different experiments in which the velocity variance and correlation time vary.

A similar series of experiments conducted in the NCOM demonstrates that the suggested LSGS model can significantly improve the particle transport prediction in OGCMs as well.

2. Numerous Monte Carlo experiments with different number of drifters clearly demonstrate that the suggested OI scheme for the Eulerian velocity given Lagrangian observations performs essentially better than the simplest assimilation procedure used before (Molcard et al, 2003, Ozgokmen et al, 2003). An example of the interpolation error behavior is shown in Fig. 2 for 49 drifters in region 20x20 km

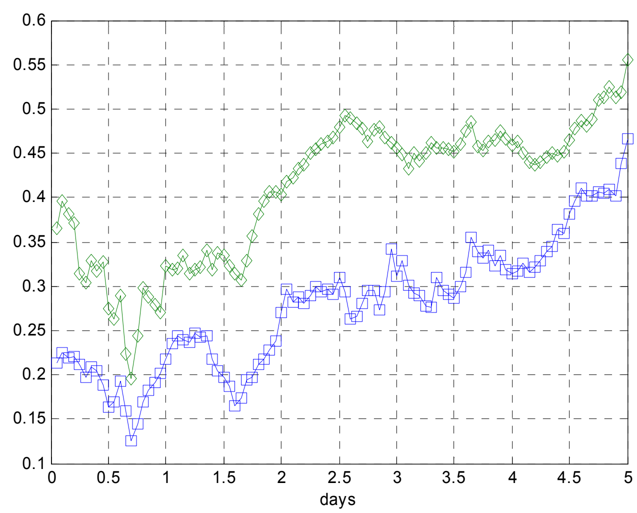

Figure 2. Relative error of interpolation for the suggested OI (blue) and the simplest one (Molcard et al,2003)

The interesting effect is found and explained that at some point the increasing density of drifters does not improve the velocity estimate.

3. First, we showed that the velocity spatial correlation radius, R, which is a key parameter in multi particle LSMs, can be efficiently estimated from only two drifter trajectories started close enough one to another. Fig.2 demonstrates that for the exponential covariance and different weight of the potential and solenoidal forcing.

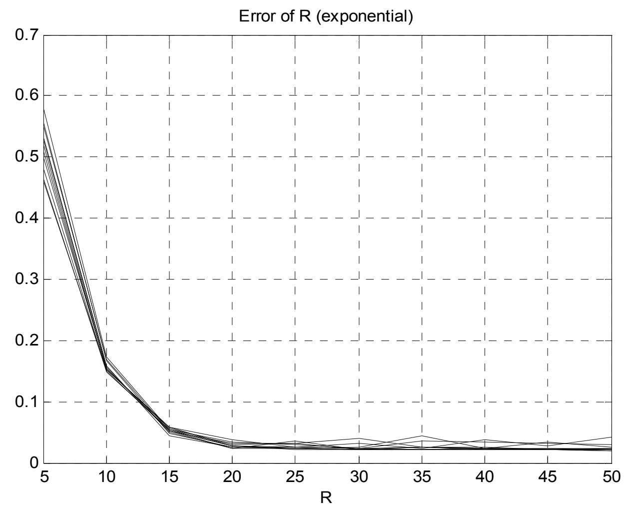

Figure 3. Dependence of the estimation error of R on R itself for different ratio of the solenoidal and potential parts of the forcing

Next, we showed that in the case of unknown spectral slope, ν, of the forcing, it can be satisfactorily estimated as well. The estimate of R in this case becomes worse, but still remains reasonable. Given estimates of R and ν other important physical characteristics of the Lagrangian turbulence can be found. It is demonstrated that the relative dispersion and Lyapunov exponent can be well estimated from a pair of trajectories.

4. The conducted validation of the stochastic eddy-reach velocity field (Cinlar flow) via the surface velocity radar data leads to a reasonable parameterization of the eddy birth/death process. Comprehensive estimates of the eddy parameters are obtained which potentially can be used in parameterization of the sub-grid-scale turbulence in OGCMs.

IMPACT/APPLICATIONS

1. The validated algorithm of improving the drifter position prediction can be suggested as an operational tool in rescue and search operations as well as in optimal deployment of drifter clusters.

2. The suggested new OI procedure for estimating Eulerian velocity given Lagrangian observations can be used as an element in building comprehensive assimilation algorithms explicitly involving OGCM.

3. A principal possibility of estimating mixing parameters such as relative dispersion and Lyapunov exponent from a single pair of drifter trajectories is proven. Thereby the door is open to revise archive Lagrangian data sets in order to improve Lagrangian statistics via the new estimation tools.

TRANSITIONS

The developed model trajectory correction assimilation algorithm was used in RSMAS to test it in NCOM circulation model. The new OI algorithm is planned to implement for Lagrangian data assimilation in OGCMs by the same group in RSMAS.

RELATED PROJECTS

1. “Predictability of Particle Trajectories in the Ocean”, ONR, PI T.Ozgokmen , RSMAS, N00014-05-1-0095

2. “Lagrangian turbulence and transport in semi-enclosed basins and coastal regions”, ONR, PI A Griffa, RSMAS, N00014-05-1-0094

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1. A. C. Haza, L. I. Piterbarg, P. Martin, T. M, Ozgokmen, and A. Griffa, (2006), A Lagrangian subgridscale model for particle transport improvement and application in the Adriatic Sea, “Ocean Modeling”, in revision

2. L.I. Piterbarg, (2006), Optimal estimation of Eulerian velocity field given Lagrangian observations, submitted to “Applied Mathematical Modeling”

3. L.I. Piterbarg, (2006), Parameter estimation in multi particle Lagrangian stochastic models, submitted to “Monte Carlo Methods and Applications”

4. M.I.Caglar, T.M. Ozgokmen, and L.I.Piterbarg, (2006), Parameterization of submeso-scale eddy-rich flows using a stochastic velocity model, “J. Atmospheric and Oceanic Technology”, in press

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